



# **Deep Space Climate Observatory, Earth Science Instrument Overview**

Version 1  
June 28, 2016

<b>1.0</b>	<b>MISSION INTRODUCTION.....</b>	<b>3</b>
1.1	ORBIT.....	4
<b>2.0</b>	<b>EARTH POLYCHROMATIC IMAGING CAMERA (EPIC) .....</b>	<b>6</b>
2.1	TELESCOPE .....	7
2.2	FILTER WHEEL AND SHUTTER.....	8
2.3	CHARGE COUPLED DEVICE & INSTRUMENT SPECTRAL SENSITIVITY .....	9
2.4	EPIC PRODUCTS.....	13
<b>3.0</b>	<b>NIST ADVANCED RADIOMETER (NISTAR).....</b>	<b>14</b>
3.1	RADIOMETER ASSEMBLY OVERVIEW .....	15
3.1.1	<i>Filter Wheel.....</i>	<i>16</i>
3.1.2	<i>Shutters.....</i>	<i>18</i>
3.2	NISTAR PRODUCTS .....	19
3.2.1	<i>Level 1A.....</i>	<i>19</i>
3.2.2	<i>Level 1B.....</i>	<i>19</i>

## 1.0 MISSION INTRODUCTION

The Deep Space Climate Observatory (DSCOVR) is a space weather and Earth science spacecraft situated at the Earth-Sun Lagrange point (L1). Launched on February 11<sup>th</sup>, 2015, DSCOVR arrived into orbit on June 7<sup>th</sup>, 2015. The spacecraft is managed by National Oceanic and Atmospheric Administration with NOAA handling the space weather instruments and day-to-day operations, and the National Aeronautics and Space Administration (NASA) providing the Earth science data processing and space weather instrument calibrations.

The primary mission of DSCOVR is to monitor the real-time solar wind and enhance NOAA's ability to provide space weather alerts and forecasts. Its secondary mission is to enable NASA to study Earth's climate. The vantage point from L1, unique to Earth science, enables imagery with a higher spatial-temporal cadence, and the monitoring of the Earth's reflected and emitted radiation.

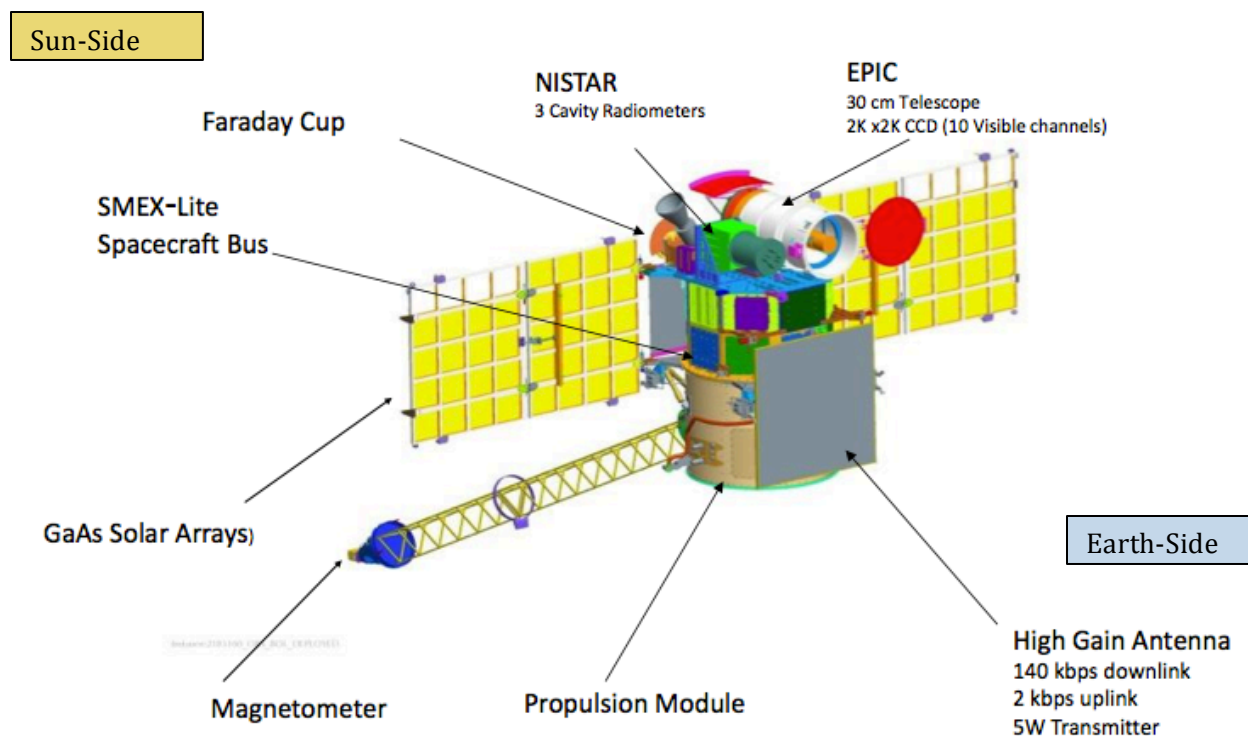
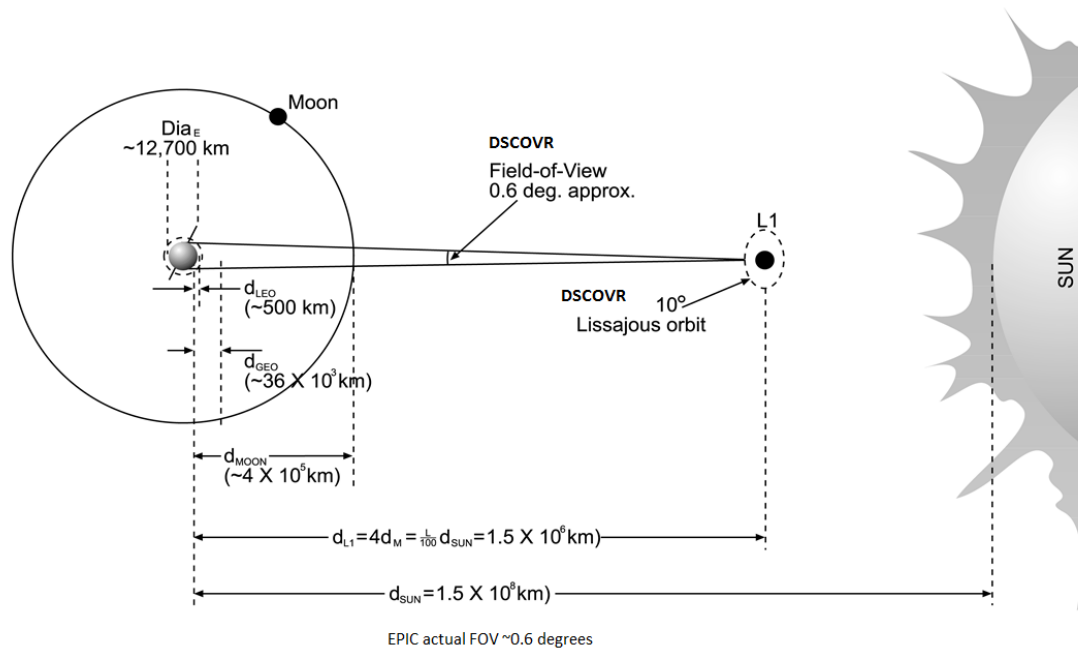


Figure 1 - DSCOVR spacecraft layout

The Earth science instruments consist of the Earth Polychromatic Imaging Camera (EPIC) and the National Institute of Science and Technology Advanced Radiometer (NISTAR). They are located “on top” of the spacecraft on its Earth-facing side in Figure 1. The solar instruments, which include the Faraday cup, Electron Spectrometer, and Magnetometer, sit on the Sun-facing side of the spacecraft. More information regarding these instruments can be found in separate documents.

## 1.1 ORBIT



**Figure 2 - Schematic of DSCOVR orbit at Lagrange-1 showing the Earth viewing geometry**

Above is a figure describing DSCOVR's view of the Earth from the orbit around the Earth-Sun Lagrange 1 point. The L1 point is located at about 1.5 million kilometers from the Earth. The orbit is a non-repeating Lissajous figure, tilted with respect to the Earth's ecliptic plane. It takes 6 months for one circuit, during which the apparent size of the Earth varies, with a nominal viewing size of .5 degrees. During the life of the mission, the orbital shape will change from an approximate ellipse, to a circle, and the back to an ellipse in about 5 years. The orbit at L1 is quasi-stable, and requires periodic correction from the onboard hydrazine rocket motors. Below are figures representing the Lissajous orbit.



### Lissajous Orbit Viewed from Earth

(15°,15°,4 °) Class 2/CCW, 5 years  
6 month period for a single loop

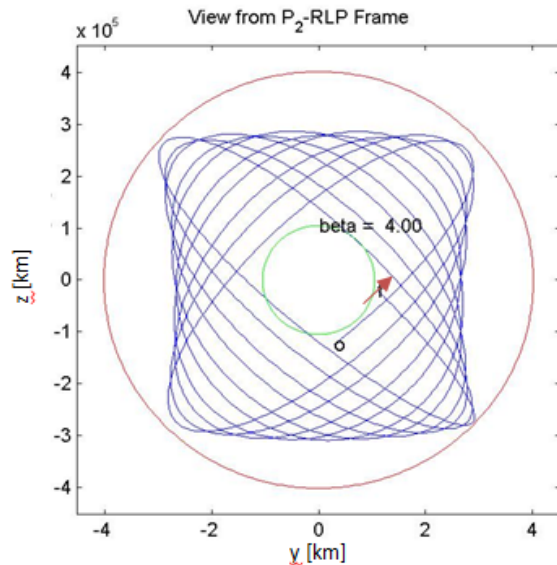


Figure 3 - Size and angles for a non-repeating Lissajous orbit at L1. Each approximate circuit takes 6 months. The actual orbit is irregular because of perturbations from the Moon and periodic orbit maintenance adjustments.

### Angle between Sun-Earth line & position vector from Earth to Vehicle (SEV Angle)

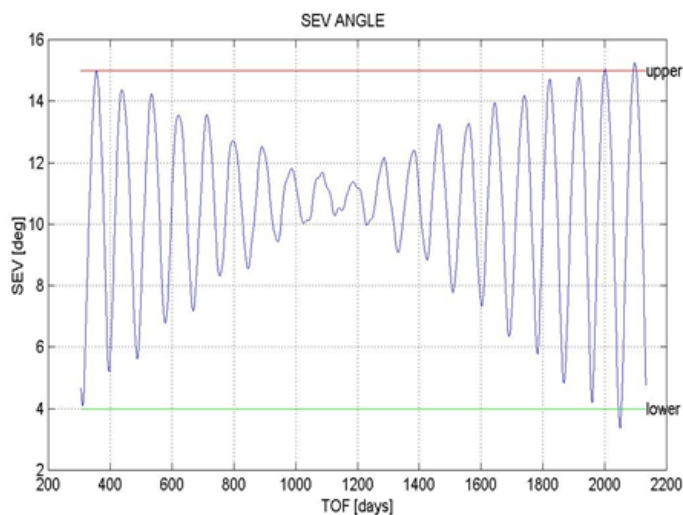


Figure 4 - Diagram of Solar/Earth/Viewing angle (SEV) over time in the orbit

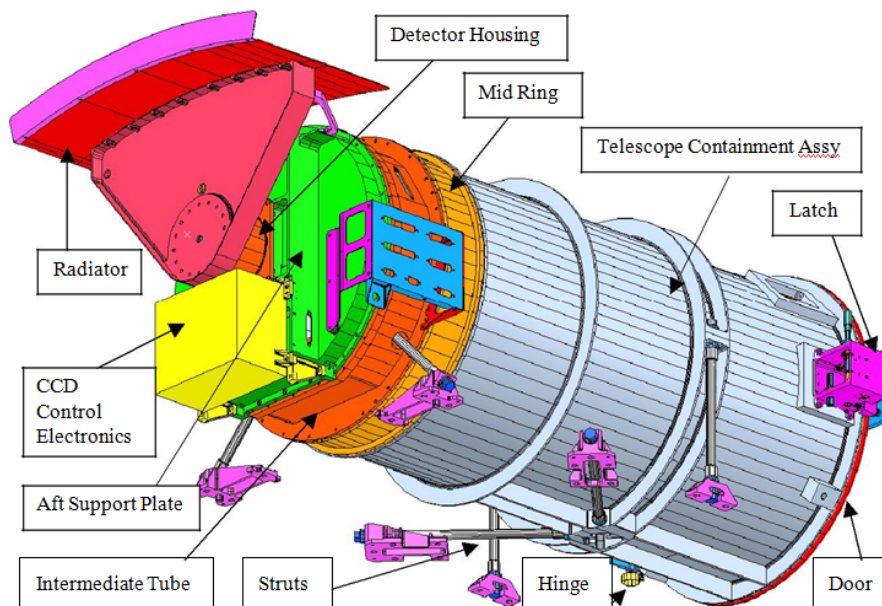
In Figure 4, the changes in the Sun-Earth-Viewing angle are represented. The effect of the SEV angle can be seen in the EPIC images, as the location of the solar terminator switches from East to West over the course of an orbit. Although DSCOVR is oriented nominally so it is pointed at the Earth, the spacecraft occasionally performs calibration maneuvers that involve off pointing at different angles.

The planned mission life of DSCOVR is 5 years.

## 2.0 EARTH POLYCHROMATIC IMAGING CAMERA (EPIC)

The Earth Polychromatic Imaging Camera (EPIC) is a 10-channel spectroradiometer onboard DSCOVR. After the arrival of DSCOVR at L1 on June 7<sup>th</sup>, 2015, EPIC's door was opened and started imaging on June 9<sup>th</sup>.

From its vantage point, EPIC has a unique view of the Earth, taking images of the fully lit surface at 1-1.6 hour intervals per day.



**Figure 5 - EPIC exterior design. The filter wheel can be seen in green and the CCD is contained within the orange section labeled "Detector housing"**

The EPIC instrument consists of a 2048x2048 charge-coupled device (CCD) attached to a 30cm f/9.6 Cassegrain telescope (Figure 2). Using a filter wheel, it samples at 10 channel narrow-band ranges from 317.5nm to 780nm (Table 1). These bands provide the ability to generate a variety of science products, including ozone, sulfur dioxide, aerosols, vegetation, and cloud height.

**Table 1 - EPIC Wavelengths and main data products**

<b>Table 1 EPIC Wavelengths and main data products</b>		
<b>Wavelength (nm)</b>	<b>Full Width (nm)</b>	<b>Primary Application</b>
317.5 ± 0.1	1 ± 0.2	Ozone, SO <sub>2</sub>
325 ± 0.1	2 ± 0.2	Ozone
340 ± 0.3	3 ± 0.6	Ozone, Aerosols
388 ± 0.3	3 ± 0.6	Aerosols, Clouds
443 ± 1	3 ± 0.6	Aerosols
551 ± 1	3 ± 0.6	Aerosols, Vegetation
680 ± 0.2	2 ± 0.4	Aerosols, Vegetation, Clouds
687.75 ± 0.2	0.8 ± 0.2	Cloud Height
764 ± 0.2	1 ± 0.2	Cloud Height
779.5 ± 0.3	2 ± 0.4	Clouds, Vegetation

## 2.1 TELESCOPE

The Earth viewed by EPIC has a nominal width of approximately 0.5 degrees. The instruments total field of view (FOV) is 0.62 degrees. Because of the Lissajous orbit about L1, the apparent size of the Earth changes slightly during the 6-month orbital period. Figure 5 shows the size of the Earth relative to EPIC's field of view FOV. While the pixel size samples the Earth near the equator at 8 x 8 km<sup>2</sup>, the spatial resolution of an EPIC image is about 12x12 km<sup>2</sup>. The resolution is reduced by the



**Figure 6 - EPIC image demonstrating the CCD field of view angle versus the angular size of the Earth**

The schematic below of the telescope (Figure 7) shows the primary and secondary mirrors, focusing or field lens group (FLG), and the filter wheel location just in front of the CCD. The purpose of the FLG is to reduce the aberrations inherent in a Cassegrain design. In the EPIC system, the FLG is physically located between the primary mirror and the filter wheels. Along with new filters and anti-reflection coatings, the FLG was one of the optical elements replaced with an improved design to reduce stray light.



The DSCOVR instruments and spacecraft are shown in Figure 1, demonstrating their relative size. EPIC was launched with the exterior lens door closed. The door was opened once when the spacecraft achieved orbit at L-1.

Inside the telescope is a double filter wheel with 12 spaces for 10 filters plus 2 open holes (Figure 8) arranged with six holes in each wheel. Computer controlled stepper motors position the filters in a pre-determined sequence that can be altered by onboard or ground



commands.



Figure 8 - The EPIC double filter wheel

In front of the filter wheels there is a shutter mechanism (Figure 9). The shutter blade contains 3 slots: the narrow and medium width slots are used to produce 2 to 10 ms exposures, respectively; the wide slot is used for exposures > 46 ms. For 10 to 46 ms exposures, the shutter blade is moved so that the middle sized slot crosses the light path in a single motion. For exposures longer than 46 ms, the wide slot is used. While in the open position, the blade slows down, then speeds up to complete the exposure. For an exposure longer than about 60 ms, the blade comes to a complete stop in the open position, prior to closing.

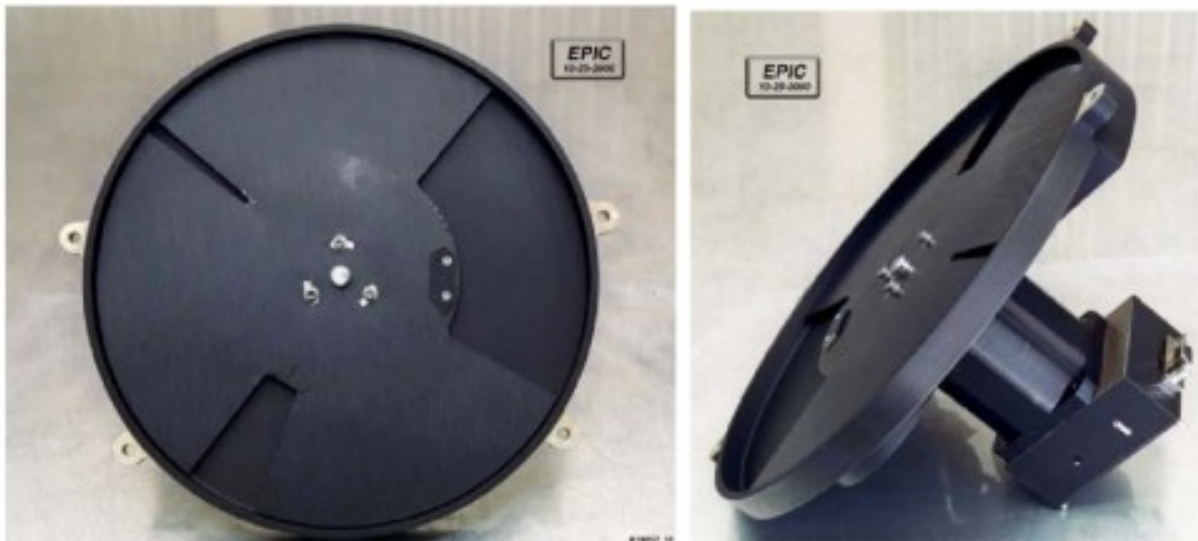


Figure 9 - Shutter wheel assembly showing 3 shutter positions; Narrow, Medium, and Wide

## 2.3 CHARGE COUPLED DEVICE & INSTRUMENT SPECTRAL SENSITIVITY

The focal plane is a 2048 x 2048 pixel CCD, backside-thinned, backside-illuminated

and anti-reflection (hafnium) coated to optimize quantum efficiency down to 300 nm. The CCD is passively cooled to approximately -20°C on orbit to reduce dark current and other noise effects. In normal operation the CCD will be read out from opposite corners at 500 kHz, but the entire array can be read out from either side, thus providing some measure of redundancy. The CCD characteristics are summarized in Table 2.

**Table 2 - EPIC CCD characteristics**

<b>CCD characteristics</b>	
<b>CCD format</b>	2048 x 2048 pixels (3.072 x 3.072 cm square)
<b>Pixel size</b>	15 µm x 15 µm, 100% fill factor
<b>Pixel FOV</b>	1.078 arc-sec
<b>CCD type</b>	Thinned, backside illuminated
<b>Spectral range</b>	200 - 950 nm (QE > 25%)
<b>Pixel full well depth</b>	> 95,000 electrons
<b>Readout</b>	Single or dual (diagonal corners)
<b>Pixel readout rate</b>	500 kHz
<b>CCD operating temperature</b>	-40°C, by passive cooling
<b>System Noise: top analog train</b>	sigma = 1.6 DN
<b>System Noise: bottom analog train</b>	sigma = 3 DN
<b>Dark current</b>	<5 electrons per second per pixel

The CCD quantum efficiency is shown in Figure 10 showing a reasonable response at both ends of the desired spectrum, 317 nm (80%) and 800 nm (50%).

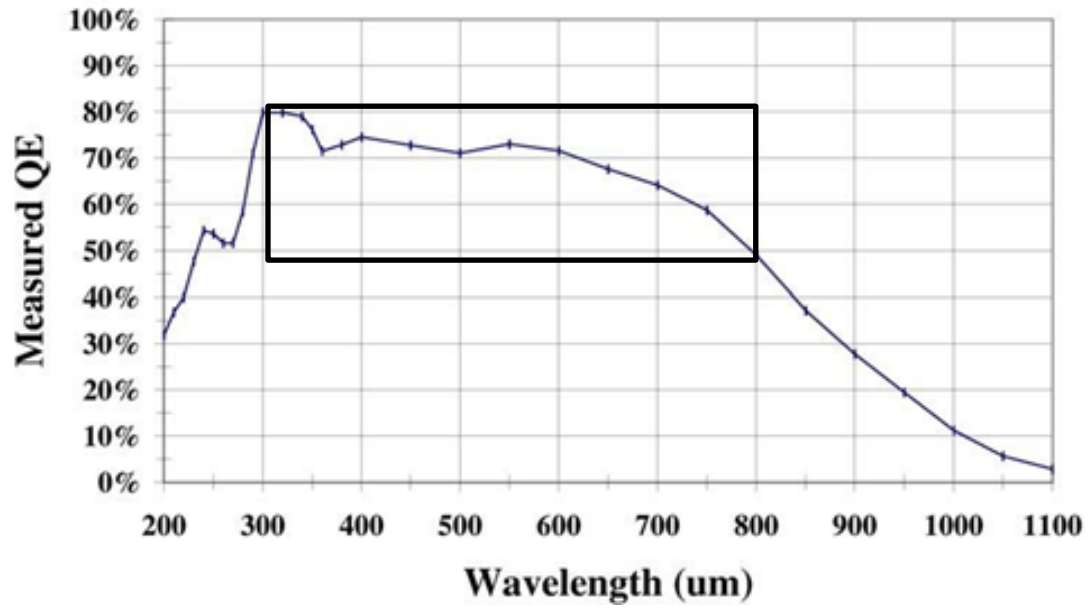


Figure 10 - CCD quantum efficiency showing the useful range of the EPIC instrument within the box

The measured telescope transmission is shown in Figure 11, which varies between 70 and 80% of the useful range of EPIC

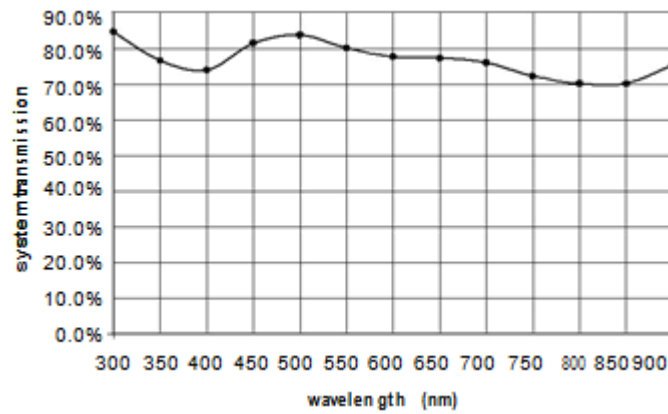


Figure 11 - Telescope transmission in percent

The mirrors are made from Zerodur with an aluminum coating and a SiO<sub>2</sub> coating on the primary mirror and aluminum overcoated with MgF<sub>2</sub> coating on the secondary mirror. The structure maintaining the optical separation between the primary and secondary mirrors (metering tube) is a graphite composite cylinder designed to exhibit 0 CTE (coefficient of thermal expansion). The mechanical structure supporting the primary and secondary mirrors (between the mirrors and the metering tube) is Invar 36 to minimize thermal expansion properties.

The EPIC filters were refurbished to have improved antireflection coatings and better out of band rejection (light from other wavelengths). The mean filter transmission functions are shown in Figure 12. For most science products, the measurements from each filter are combined in pairs as a ratio or difference. An exception is for estimating cloud reflectivity using 340 or 388 nm, where a single channel is used.

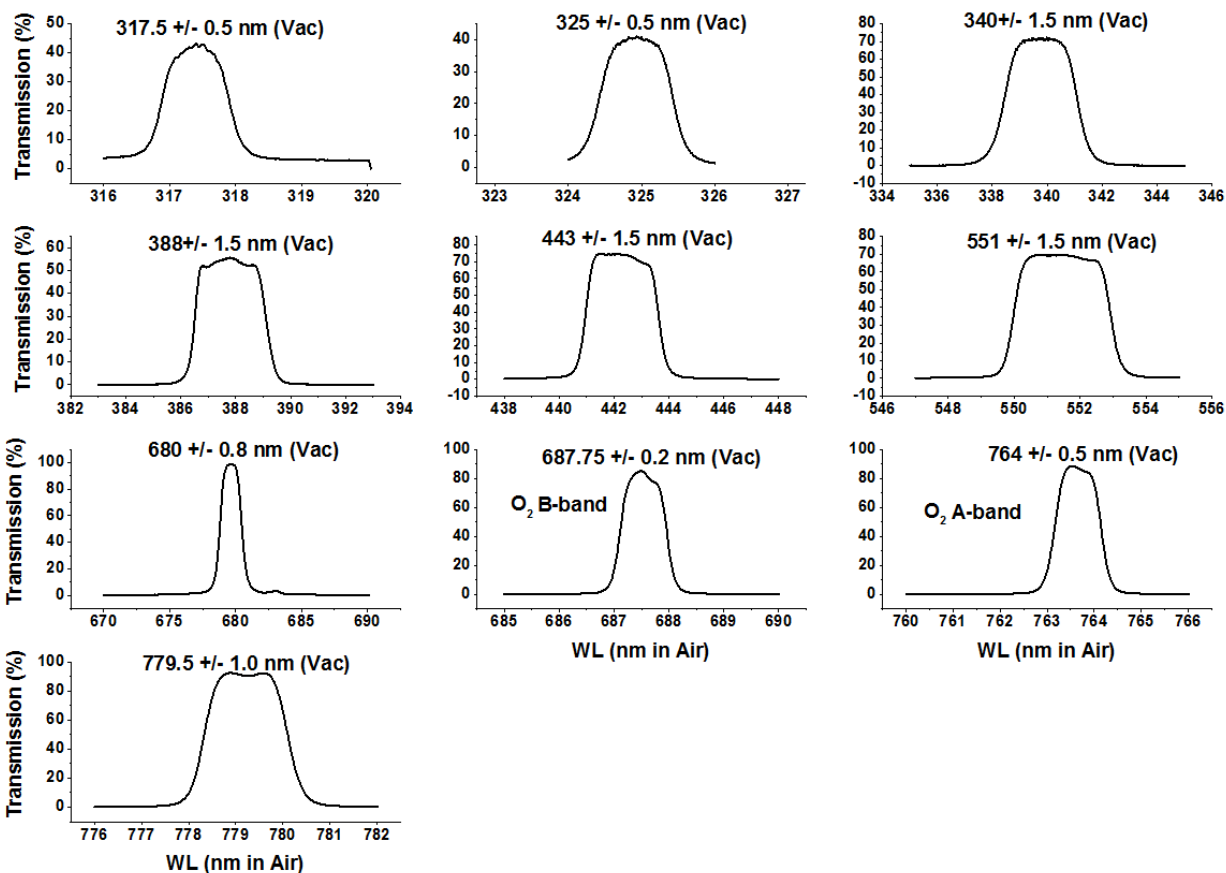


Figure 12 - Mean filter transmission functions in percent



In order to be useful, certain corrections must be applied before either images or science products can be obtained. The major corrections are for “flat-fielding” and stray light. “Flat-fielding” is based on measurements with a uniform light source to measure the differences in sensitivity for each of the 4 million pixels. The resulting correction map is applied to the measured counts from the CCD. Stray light was measured in the laboratory using a series of small diameter light sources entering the telescope and being detected by the CCD. The illumination by pixels outside the main diameter of the light source was measured. A detailed matrix map was made of the entire stray light function (the effect of light directed at each pixel affecting every other pixel). The stray light correction is applied to every image. Other corrections are also applied based on laboratory measurements, such as the etaloning at longer wavelengths due to interference effects between the front and back of the silicon CCD which is semitransparent for wavelengths longer than 600 nm (red and near-IR). Out of band leakage is very small (0.04 percent for 325 nm).

## **2.4 EPIC PRODUCTS**

EPIC data sets produced and sent to the Atmospheric Science Data Center consist of a level 1A, a level 1B product, and a color image. A level 1A and level 1B product each consists of 1 set of images. For EPIC, an “image” is defined as a single image taken of one band. A “set” is defined as 10 images (1 image per band) taken during a single viewing period. A viewing period is typically within 8 minutes length and the number of viewing periods is between 13-22 per day.

In level 1A, the EPIC images have been processed from the spacecraft telemetry, decompressed, and corrected to remove artifacts. This includes the flat fielding correction, searching for brightened or “enhanced” pixels, read wave corrections, offsets, latency, slope, and non-linearity corrections, and calibration for temperature. The images have been normalized into units of “counts per second”; the number of photos that the detector measured over time. The level 1A products are in the original pixel grid configuration and orientation as measured by the sensor.

For level 1A, there is appended geolocation information. This includes latitudes and longitudes, as well as per-pixel sun and instrument viewing angles. Metadata is included that describes the sensor configuration at the time the image was taken, as well as ancillary geolocation and spacecraft orientation information.

For level 1B, the geolocation is applied. The level 1A images are reprojected into one fixed grid for the set. This corrects for the location drift that occurs due to the rotation of the Earth and the motion of the spacecraft over the viewing period. After this process, the pixels in the different bands will have the same physical location across the set.

The same ancillary data and metadata is included for the level 1B as was in the level 1A.

### 3.0 NIST ADVANCED RADIOMETER (NISTAR)

The National Institute of Standards and Technology Advanced Radiometer (NISTAR) instrument is composed of three cavity radiometers and one photodiode channel. The instrument is designed to take advantage of DSCOVR's location at the L1 point to measure the energy emitted and reflected by the Earth. By measuring the Earth's energy balance, the solar energy striking Earth minus what is reflected and radiated into space, NISTAR will improve our understanding of the effects of changes caused by human activities and natural phenomena. NISTAR will provide the first direct measurements of the radiant power reflected by the full Earth disk with a goal of 0.1% accuracy. NISTAR will make simultaneous measurements in three bands plus one reference.

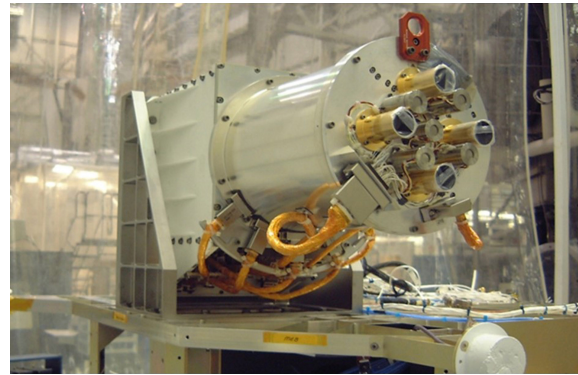


Figure 13 - NISTAR instrument

- Band-A (0.2 to 100 $\mu$ ) - visible plus far infrared channel to measure total radiant power coming from the Earth
- Band-B (0.2 to 4 $\mu$ ) - solar channel to measure reflected solar radiation
- Band-C (0.7 to 4 $\mu$ ) - near infrared channel to measure reflected infrared solar radiation
- Photodiode (.3 to 1 $\mu$ ) - channel to be used as an on-board calibration reference

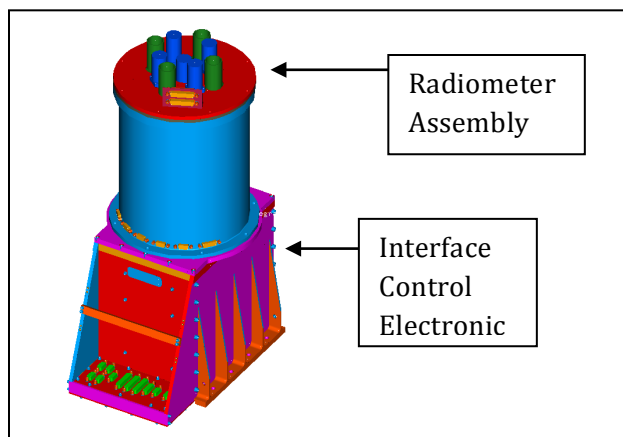


Figure 14 - NISTAR exterior schematic

NISTAR, pictured in Figure 14, consists of the Radiometer Assembly (RA) and the Interface and Control Electronics (ICE) module. The RA houses three electrical substitution radiometers with separate optical shutter/contamination doors for each, a silicon photodiode (PD) filter detector, a heat sink (HS), and a twelve-position filter wheel (FW). The ICE consists of the flight computer, motor driver, interface and housekeeping electronics.

NISTAR has a radiometer Field of View (FOV) of  $1^\circ$  and Field of Regard (FOR) of  $\sim 6.7^\circ$ . Because of the FOR, the NISTAR boresight must be  $3.5^\circ$  away from a light source to prevent light from that source entering the instrument. This is important for operations such as dark space calibration. NISTAR is aligned with the Earth Polychromatic Imaging Camera (EPIC) camera boresight, another scientific instrument mounted on the DSCOVR observatory.

### 3.1 RADIOMETER ASSEMBLY OVERVIEW

The RA depicted in Figure 16 consists of three receiver cavities that are mechanically supported from a surrounding HS. The receivers are shaped into a cavity for enhanced absorption. Three precision apertures are mounted on the HS directly in front of each of the three receiver cavities. The Photodiode Assembly, which consists of the photodiode telescope and photodiode, is also mechanically supported from the HS. The mechanical enclosure for the receiver cavities, photodiode, and heat sink consists of the basic mechanical structure, four shutters and one filter wheel (including motors, drivers, limit detectors and associated electronics).

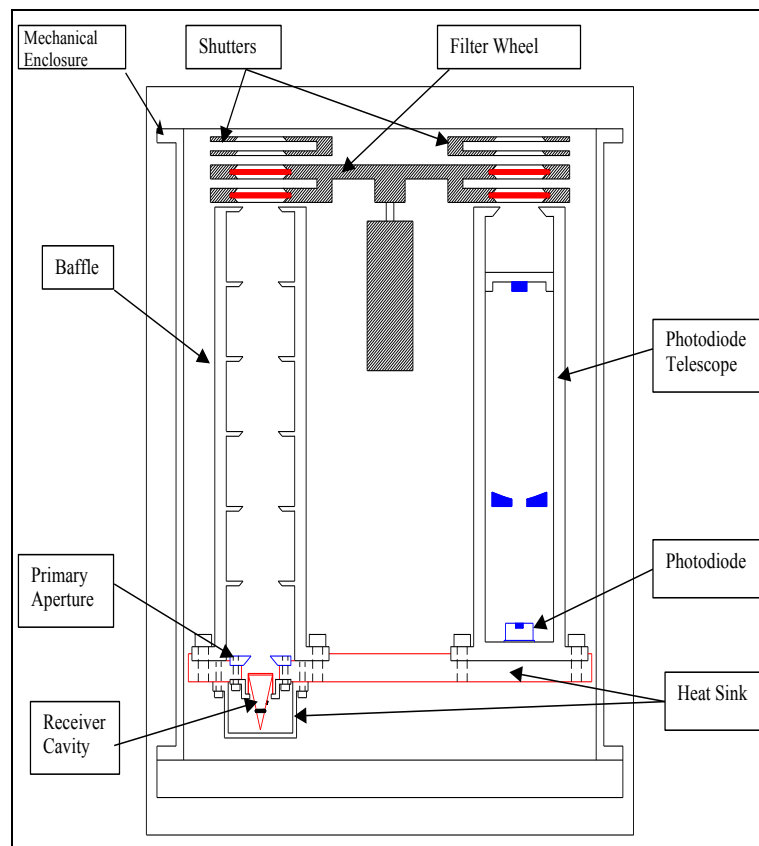


Figure 15 - Radiometer cross section

The differential temperature between the Receiver Cavities (RC) and the HS is actively controlled at a fixed operating point by an electronic servo loop. Also, the HS is actively temperature controlled at a fixed absolute temperature by a separate electronic servo loop. The optical power entering the cavity when the shutter is opened is measured by monitoring the applied electrical heater power required to maintain the RCs at a fixed operating point.

### **3.1.1 Filter Wheel**

The filter wheel is a dual level wheel with twelve optical positions numbered 1 through 12 each capable of holding two filters in series. The filters are 25 millimeters (mm) in diameter and are made of fused silica with multi-layer coatings. There are a total of six locations with filters (three each for Band-B and C), and six locations that are open (Band-A) as illustrated in [Figure 16](#). Typically, the filter transmission in space will degrade with exposure. Ultraviolet radiation, oxygen or outgassing contaminants will change the filter. Having multiple filters for each band and using one of the filters in each band 99% of the time and then switching to the others for short periods of time will allow degradation of the filters to be tracked.

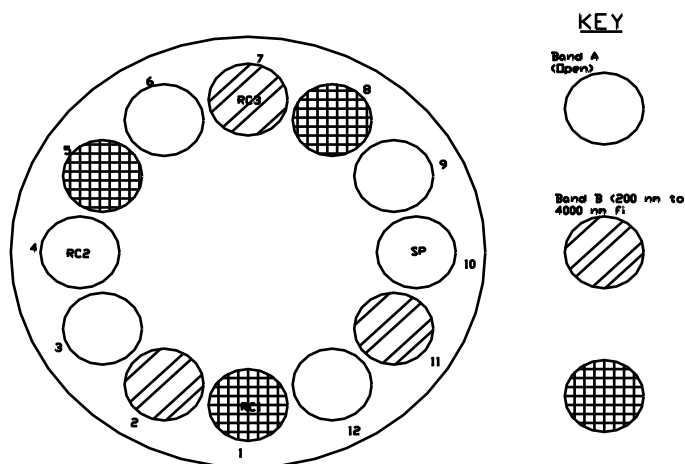


Figure 16 - Filter wheel position diagrams

Table 3 and Table 4 is a key that correlates the filter wheel position number to the positions of the various filters over each cavity. The normal position for the wheel is at a filter wheel step number of 3.

Table 3 - Filter wheel position versus filter wheel number, part 1

Detector	FW Steps					
	3	102	202	302	402	502
RC1	1C	12A	11B	10A	9A	8C
RC2	4A	3A	2B	1C	12A	11B
RC3	7B	6A	5C	4A	3A	2B
Photodiode	10A	9A	8C	7B	6A	5C

Table 4 - Filter wheel position versus filter wheel number, part 2

Detector	FW Steps					
	602	702	802	902	1002	1101

<b>RC1</b>	7B	6A	5C	4A	3A	2B
<b>RC2</b>	10A	9A	8C	7B	6A	5C
<b>RC3</b>	1C	12A	11B	10A	9A	8C
<b>Photodiode</b>	4A	3A	2B	1C	12A	11B

The filter wheel has two mechanical limits detectors located at positions 0 and 1103. These are in place to keep the filter wheel from being able to make more than one revolution in either direction. If the filter wheel is moved so that the limit detector is hit during its motion, the filter wheel will be re-calibrated automatically and will return to position 3 if the "closed" (position 0) limit switch was hit or it will be returned to position 1101 if the "open" (position 1103) limit switch was hit. The limit detectors have a lifetime limit of 25,000 hits.

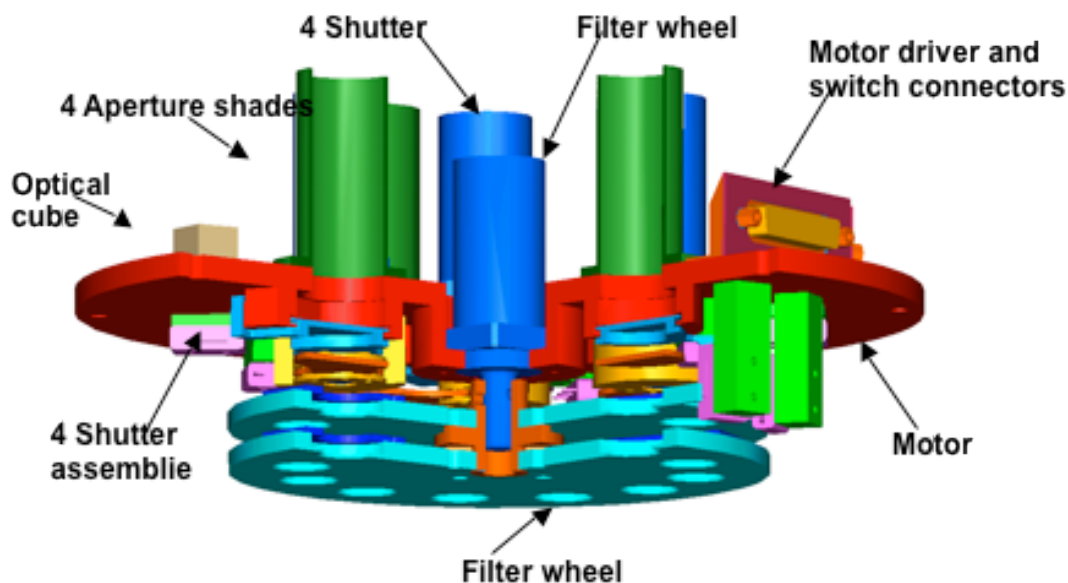


Figure 17 - Filter wheel and shutter assembly

### 3.1.2 Shutters

Mechanical shutters are located at the top of each RC and the PD to prevent contamination.

Each shutter has two mechanical limits detectors located at software shutter position numbers 0 and 200. These are in place to keep the shutters from moving too far into the mechanical enclosure. If a shutter is moved so that the limit detector is hit during its motion, the shutter will be re-calibrated automatically and will return to position 2 if the “closed” (position 0) limit switch was hit or it will be returned to position 198 if the “open” (position 200) limit switch was hit. The limit detectors have a lifetime limit of 25,000 hits.

The NISTAR flight software has the ability to autcycle selected shutters. This autcycling opens and closes only the selected shutters at a selected period.

## **3.2 NISTAR PRODUCTS**

NISTAR data sets produced and sent to the Atmospheric Science Data Center consist of a level 1A, and a level 1B product. Level 1A consists of the science, engineering, and calibration data for the instrument. Level 1B are summary products.

### **3.2.1 Level 1A**

Each NISTAR instrument level 1A science data product consists of one full (24 hour) day’s worth of data from four sensors, three active cavity radiometers and a photodiode which will serve both as a calibration reference for the radiometers and filters, and as a detector in the range from 320nm to 1100nm. One full day is defined as the interval of time from 12:00:00.00h UTC to 11:59:59.99h UTC the following day (ie, “Noon” to “Noon”). The data are primarily from the nearly full Earth, but can also contain lunar and star field data. Ancillary data associated with the science data include data collection time, Earth centroid coordinates, and spacecraft attitude and ephemeris.

### **3.2.2 Level 1B**

The NISTAR level 1B data products are generated from the level 1A products. The level 1B data consists of irradiance values for nearly the entire Earth. Irradiance values are separated by filter band (A, B, C) and the view object (Earth or star field). The data are collected and stored on four shutter cycle, four hours, and one day time scales. The smallest useful resolution for averaging is equal to four times the shutter cycle period, when shutter autcycle is activated. This is due to the 4-boxcar wide demodulation algorithm, which is used to extract an irradiance measurement from the radiometer power signal. The ground processing software determines what the shutter period is for each Julian day.

